SUMMARY OF SESSION E: SIMULATIONS OF E-CLOUD BUILD-UP

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PRESENTATION OVERVIEW

The session contained eight presentations and a general discussion. The different presentations of the session showed how much the field is still developing. Very different approaches can yield new results. In particular the following areas where covered

- developement of new and more sophisticated codes
- understanding of the electron cloud by use of simulations
- development of simplified approaches to predict the electron cloud build-up.

SESSION OVERVIEW

The following presentations were part of the session:

1. L. Wang, *Multipacting and Remedies of Electron Cloud in Long Bunch Proton Machine.*
2. A.Shishlo, Y. Sato, J. Holmes, S. Danilov, S. Henderson, *Electron-Cloud Module for the ORBIT Code.*
3. Y. Sato, J. Holmes, S. Danilov, A. Shishlo, S. Henderson, *Simulation of the Electron Cloud Effects for the SNS Ring.*
4. L. Wang, A. Chao, *Energy Structure of Electron Cloud.*
5. L. Wang, A. Chao, S. Kurokawa, S.S. Win, *Solenoid Effects on Electron Cloud.*
6. R. Cohen, A. Azevedo, A. Friedman, M. A. Furman, S. M. Lund, A. W. Molvik, P. Stoltz, J.-L. Vay, S. Veitzer, *Simulations of E-Cloud for Heavy Ion Fusion.*
7. P. Stoltz, S. Veitzer, R. Cohen, A. Molvik, M. Furman, J.-L. Vay, *The CMEE Library for Numerical Modeling of Electron Effects.*
8. U. Iriso, S. Peggs, *Use of Maps for Exploring Electron Cloud Parameter Space.*

They were followed by a very interesting and animated discussion.

The author has a hard to time to do justice to the excellent presentations of the session. Since these are available in written form in thses proceedings only a short summary of each talk will be given and a somewhat longer one of the general discussion.

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SUMMARY OF PRESENTATIONS

Multipacting and remedies of electron cloud in long bunch proton machine

In long proton bunches the already existing electrons are trapped inside the bunch during it's passage. They undergo a large number of oscillations in the beam field with growing amplitude in the decreasing field of the bunch tail, so they hit the beam pipe at the end of the bunch. Comparison of analytic estimates and simulations of the cloud build-up showed good agreement also with experiments. The cloud build-up depends strongly on the different beam parameters.

Finally possible remedies for the electron cloud were described, mainly the use of clearing electrodes and solenoids. It is interesting to note that in the case of the clearing electrode a too high clearing potential can actually induce multipacting.

Electron-Cloud Module for the ORBIT Code

The ORBIT code is being extended by a module that is capable of simulating the electron cloud effects. It has been chosen to extend ORBIT, rather than to write a new program, since this code provides all the necessary accelerator physics. The new module is very self contained in order to minimise the number of interfaces to the existing code. It can easily be extended by classes defining geometries and fields. The code is capable of running on parallel computing systems. The benchmarking of the code with analytic results (in particular for the tracking of particles) showed very good agreement.

Simulation of the Electron Cloud Effects for the SNS Ring

The new package that implements the electron cloud effects in the ORBIT code has been carefully benchmarked. The routine simulating the secondary emission of particles from the surface gives results very similar to the POSINST code, but some small deviations are observed. The first main test case for the field solver and tracker is the transverse deflection of protrons by a small and not very dense electron cloud. The agreement between simulation and calculation is very good except for a tiny difference, which is likely caused by the limited spacial resolution due to the use of cells. A comparison of the simulation of the growth rate of a two-stream instability showed reasonable but not perfect agreement (within 20%) with the analytic result.

Energy structure of electron cloud

The energy spectrum of the electron cloud shows certain bands with a reduced electron density. This effect can be explained by the passage of more than one bunch during the oscillation of a cloud electron from one side of the beam pipe to the other. The phenomenon can be observed in the KEK b-factory.

Solenoid effects on electron cloud

An electron cloud of sufficient density can lead to an instability of the beam. One of the possiblities to suppress the build-up of the cloud is the use of solenoids in drift regions. Due to the longitudinal magnetic field, low energy electrons that are close to the beam pipe will be confined to stay close to the wall. Simulations show that a homogeneous field is best. If the fields of real solenoids are used in the simulation it is advantageous to orient subsequent solenoids in the same direction rather than in alternate ones. Experiments demonstrate a reduction of the electron by a factor > 50.

The electron cloud can give rise to a multi-bunch instability; usually two modes can be excited. The use of solenoids can change the frequency of these modes; one will move up in frequency the other down.

Simulation of e-cloud for Heavy Ion Fusion

A number of features are different for accelerators for heavy ion fusion and most other accelerators. Among them the fact that the former are linacs and that most of the beam pipe is inside of quadrupoles. Particular difficulties arise from the fact that very long timescales (the passage time of a pulse) and short time scales (the cyclotron rotation of the electrons in the quadrupole fields) need to be considered simultaneously in a self-constent way.

Simulations showed that the beam remains usually quite stable even in the presence of different electron cloud distributions; but mild instabilities might occur in one of the cases.

The CMEE Library for Numerical Modeling of Electron Effects

The CMEE (Computational Modules for Electron Effects) was presented. This library aims to provide a number of modules for the use in electron cloud simulations and other fields. Currently a module is available which implements the secondary particle production due to impacting electrons (based on POSINST) and another package is used as a basis for the ion-induced electron yield. Further modules to be implemented are:

- ion induced electrons
- neutral desorption
- impact ionization
- ion scattering

The integration of the available routines into programs should be quite simple.

Use of maps for exploring electron cloud parameter space

The goal to determining the optimum distribution of the bunches in RHIC, in order to minimise the electron cloud, is very time consuming if done by straight forward simulations. It was observed that the evolution of the electron cloud during the passage of a bunch train can be easily represented by a transfer map relating the densitiy ρ_{n+1} at step $n+1$ to the one at step n via a third order polynomial. The coefficients of the polynomial depend on the charges of the last two bunches. For small cloud densities a linear map can be used. In this case the optimum distribution can be easily determined to be the most sparse one.

In RHIC the observation was made that sometimes the vacuum pressure drops abruptly as the beam intensity is reduced. The question was raised if simulations can reproduce this feature.

DISCUSSION

During the discussion an attempt was made to review the current status of the simulation codes and their predictions. The main obstacles to further improvement and the best strategy were discussed.

Two main reasons make it essential that codes are benchmarked. First, they are developed to gain understanding of problems which cannot be addressed with analytic means. Consequently, judging the results of the simulations is not necessarily straightforward. Second, if a program can not be based completely on known physics this has major implications. In this case, the simulation must be compared to experiments in order to determine how the unkown physics processes can be modelled. Only after this step predictions can be made. For these reasons benchmarking with analytic predictions, other codes and experiments is important for all codes.

Relevant Physics

Some of the physics involved in the electron cloud buildup is well understood. This is the case for the electromagnetic fields created by the beam and the electron cloud. The same is true for the solution of the equation of motion in the fields. The knowledge of the interaction of the electrons with the surface is much less well understood. This is due to two main reasons. First, the seconday emission (including reflection etc.) for a perfectly known surface is in itself a difficult problem. Second, the actual surface conditions are known only with very limited accuracy. The surface properties are changing due to many different effects.

A suggestion made to overcome the problem of the unknown surface properties was to use specially prepared surface where one can hope that the propoerties do not change too rapidly. The other solution would be to measure the properties during or at least immediately after the experiment. This is however quite difficult in practice. An attempt to use the above approaches are the installation of NEG coated beam pipe in the SPS and an in-situ secondary emission yield measurement in the same machine. Another constraint on the secondary emission model can arise from the measurement of the survival time of the electrons of the cloud.

The attempt to provide a library of surface simulation routines can be very helpful for the improvement of the surface modelling. First, it allows easy integration of these models into codes in the form of well tested modules and it will simplify benchmarking. It seems important that competing models are included in this library.

Since the number of parameters in the surface model can be quite large, the question was raised, which of these parameters have significant effects on the results. If the number of free parameters can be contraint by identifying less important ones, the benchmarking with experiments may be simplified.

Numerics and Computers

The simulations of the electron cloud build-up can be quite time consuming. This is in particular the case for self consistent simulations in which the effect of the cloud on the beam is also taken into account. In the case of instability calculations numerical effects can also have a significant impact on the results so that their very careful analysis is important.

Generally it can be observed that the quality of the simulation codes is improving due to the very careful choice of algorithms used, the introduction of parallel computing and by a more modular design. The modular design can be important in two ways. First, the code should consist of modules. This eases the development and allows for example simple integration of routines from a library, e.g. the one of presentation in talk 7. Second, the code may need to be easily integrable into some large framework by representating a module itself. The module for the ORBIT code is a good example, see talk 2.

Benchmarking

Benchmarking of the electron build-up codes is vital. Different stages of benchmarking exist:

- comparison of the code to a full analytic model
- comparison of the code to an approximate analytic model
- comparison of one code to another
- comaprison of a code to experimental data.

The comparison of the program to a full analytic model is ususally already done during the developement phase. It is obvious that this type of benchmarking cannot be used for the actual problems one wants to explore with the program—otherwise one could have resorted to analytical calculations alone. However, many parts of the code can be tested in this fashion and experience tells that many bugs have been found by this method.

Comparison of a program to an approximate analytical model allows to benchmark the code for somewhat more complex problems. The comparison of the results is somewhat more complicated than in the previous case, since, obviously, the program should only approximately yield the analytic result.

A comparison of different programs is essential. It is the only way to benchmark the code for the interesting problems, save for the quite time-consuming comparison to experiments.

The final step of benchmarking is the comparison of the program results to experiments. While this is the moment of truth, it is not an easy step. It can be hard to measure the relevant parameters due to limitations in the instrumentation and due to other sources of signals similar to the ones one tries to measure. In addition the actual conditions of the experiment (e.g. the status of the surface) may be uncertain.

Improvement of Benchmarking

In the discussion it was felt that the benchmarking of codes can be further improved even on the level of code-to-code comparison. Some test cases already exist (see `http://wwwslap.cern.ch/collective/ecloud02/ecsim/buresults.html`) but more would be useful. Also a wider participation into the benchmarking should be encouraged. Volunteers are invited to participate in the paper in preparation for EPAC. Certainly more and improved experiments will be needed.

CONCLUSION

While the session showed the significant progress in the field, more work remains to be done. In particular the importance to foster benchmarking of the electron cloud build-up simulations was stressed by the participants.

ACKNOWLEDGMENT

I would like to thank all the speakers for the exciting presentations, the audience for an animated discussion and Jean-Luc Vay for being an efficient secretary and for very useful discussion of the summary presentation.